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IGNITION OF METAL POWDERS IN COMBUSTION PRODUCTS OF MODEL FUEL

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Foreign Technology Division
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Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

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RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

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rot	curl
lg	log

GREEK ALPHABET

Alpha	Α	α	•		Nu	Ν	ν	
Beta	Β	β			Xi	Ξ	ξ	
Gamma	Γ	γ			Omicron	Ο	ο	
Delta	Δ	δ			Pi	Π	π	
Epsilon	Ε	ε	ϵ		Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ			Sigma	Σ	σ	ς
Eta	Η	η			Tau	Τ	τ	
Theta	Θ	θ	ϑ		Upsilon	Υ	υ	
Iota	Ι	ι			Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ	•	Chi	Χ	χ	
Lambda	Λ	λ			Psi	Ψ	ψ	
Mu	Μ	μ			Omega	Ω	ω	

IGNITION OF METAL POWDERS IN COMBUSTION PRODUCTS OF MODEL FUEL

A. K. Klyauzov, M. M. Arsh, F. P. Madyakin, and G. A. Filaretova

Kazan'

In recent years a significant number of studies has been dedicated to experimentally determining delay time in the ignition and combustion of many metals and metal alloys. These quantities are determined as the properties of the metal itself, just as the conditions of the experiment. The determination technique and the apparatus which is used play a significant role. We conducted studies with a method consisting basically of the following: the studied metal powder was ejected through the inner channel of a burning model fuel specimen into the flame. A mixture of ammonium perchlorate (APC) and polyisobutylene (PB) was used as the model fuel. The charges were pressed into the shape of a cylinder with an inner channel of 8 mm and an outer diameter of 22 mm. They were packed to a relative density of 0.97. To assure that the combustion front of the specimen would be parallel the inner and outer surfaces were plated with an ash-free filter layer using glue BF-2. The studied metal powders were dispersed in narrow fractions. The studies were conducted on a stand, the basic scheme of which is shown in Fig. 1. A specimen of the metal powder weighing 0.005 g was placed in the hollow of a piston, which was inserted in a cylinder and covered with a lid. A

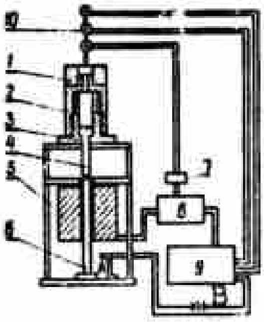

Figure 1. Basic scheme of device: 1 - specimen, 2 - cylinder lid, 3 - cylinder, 4 - piston, 5 - solenoid, 6 - solenoid shaft, 7 - small current amplifier, 8 - programmed time relay, 9 - oscillograph, 10 - photoelectric cells, (A - contact, B - dc source).

specimen, which was ignited from the upper end, was placed on the tube of the lid. Within a certain time, when the combustion front of the specimen reached the end of the tube, a programmed time relay engaged solenoid. The solenoid shaft pushed the piston to the stop. Inertia forced the metal particles from the cylinder tube into the flame.

At the moment that the piston thrust against the stop contacts A were closed and a signal was transmitted to one loop of the oscillograph. The moment of ignition of the particles was recorded by photoelectric cells located at different distances along the flame and connected to the oscillograph loop. Thus, the time from the moment that the particles began their flight until the time of their ignition τ was determined by the oscillogram. The flight times of the particles along the cylinder tube (τ_1) were determined for each powder individually before the test was begun. For this purpose a lamp was placed such that its narrow light beam passed over the end of the tube and fell upon the photoelectric cell. When the particles escaped from the tube they covered the light beam, and this was recorded on the oscillogram. At the moment that the particles began their flight contacts A were also closed and a mark made on the oscillogram. Times τ_1 were determined from the oscillogram. Ignition delay times $\tau_з$ were determined as the difference between times τ and τ_1. Each point represented the average value from ten parallel tests.

The effect of the degree of dispersion of the particles and of certain inorganic additives on ignition time of the metal was determined for powders of Mg, Al, and the alloy AM. Studies conducted in the combustion products of a model fuel with a 5%

concentration of PB (α=2.00) showed that as the size of the particle was increased quantity $\tau_з$ increased. For the same degree of dispersion the alloy AM had the least ignition delay time, Al - the greatest. The increase in $\tau_з$ as the degree of dispersion decreases is explained not only by the fact that greater heat and time must be spent in heating larger particles to the ignition temperature, but also by the fact that heat arriving per unit volume from the oxidation of the metal itself decreases. To study the effect of the inorganic additives on ignition delay time of the metal MnO_2, BaO, and V_2O_5 were selected, since their effect on the heat expansion process of APC is known. The additives were introduced into the model fuel and applied to the metal surface. The effect of the additive on ignition time was described by the ratio of $\tau_з$ without the additive to $\tau_з$ with the additive (z). As the studies revealed (Figs. 2 and 3), introducing the additive into the model fuel brought about very little change in $\tau_з$ for Mg and decreased it when it was applied to the surface of the metal particle. We observe the reverse dependence for alloy AM. The additive MnO_2 has the greatest effect on ignition delay time for both Mg and the alloy AM, BaO - the least. It should be mentioned that as the diameter of the particle increases the effect of the additive and its nature have little influence on $\tau_з$. This is explained by the fact that as the diameter of the particle increases its surface decreases, and the oxidation reactions which occur on the surface have an insignificant effect on the ignition process. In this case ignition of the particles depends basically on the combustion temperature of the model fuel ($T_г$).

The effect of additives MnO_2 and Fe_2O_3 on the combustibility of Al was studied in combustion products of a model fuel with various values of α. When MnO_2 was applied to the surface of the particles ignition time for all studied α of the fuel varied insignificantly (z≈1). When the MnO_2 and Fe_2O_3 additives are introduced into the composition of the fuel quantity z depends on value α of the fuel. This dependence has a complex form. When α≈1 the value of z is also close to 1. As α increases z grows,

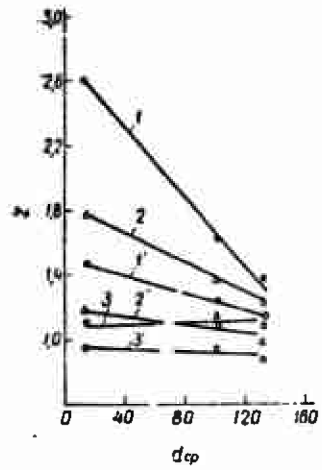

Figure 2

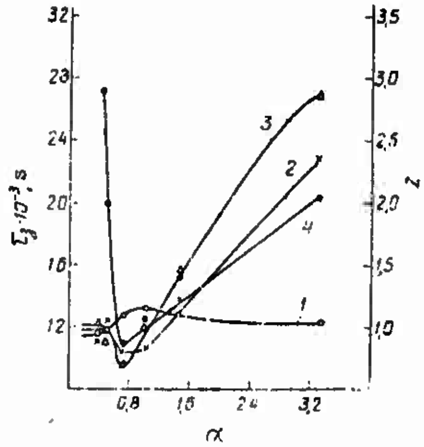

Figure 3

Figure 2 Change in relative ignition delay time z as a function of particle size for alloy AM. Additives introduced into: 1 - MnO_2, 2 - V_2C_5, 3 - BaO; additives applied to surface of particles: 1' - MnO_2, 2' - V_2O_5, 3' - BaO.

Figure 3. Effect of the nature and application method of additive on ignition delay time for various values α of the fuel: 1 - additive MnO_2 applied to surface of Al particles, 2 - MnO_2 additive introduced into composition of fuel, 3 - Fe_2O_3 additives introduced into composition of fuel, 4 - τ is a function of α of fuel.

and at α=3.43 it is equal to 2.93 for Fe_2O_3 and 2.4 for MnO_2. As the concentration of PB increases in the fuel z decreases and reaches a minimal value at α=0.74. With a further decrease in α quantity z begins to grow, and at α=0.48 z again becomes equal to 1. The effect of additives introduced into the model fuel on $\tau_з$ of the metal is the result of the effect of these additives on the composition of the combustion products of the fuel and the flame temperature with respect to the height of the flame.

The curve representing ignition delay time for Al as a function of α for the fuel (Fig. 3) has a minimum point. The least value of $\tau_з$ is reached at α<1, i.e., in combustion products with an "unfavorable" concentration of oxidizing agents and at

lower combustion temperatures. To explain this phenomenon conditional studies were made and the composition of the combustion products of model fuels was calculated.

Figure 4 shows the results of studying $\tau_з$ as a function of the combustion product parameters of a model fuel. Here $T_г$ and the percent concentration of water vapors in the combustion products of the fuel were used as the parameters. The studies showed that when T was decreased from 3260 to 2950°K ignition delay time decreases somewhat with a subsequent slow increase. At the same values of T (in a range above 2300°K) $\tau_з$ in the combustion products of a fuel with $\alpha>1$ (upper part of curve) is greater than $\tau_з$ in the combustion products of a fuel with $\alpha<1$. The concentration of water vapor in the combustion products as a function $T_г$ has the same form as for $\tau_з$. Consequently, delay time is the function of change in primarily two combustion product parameters of the fuel - $T_г$ and the concentration of water vapor. The effect of the percent concentration of water vapor in the combustion products of the fuel on $\tau_з$, as well as the connection between $T_г$ and the concentration of water vapor in the combustion products, are shown in Fig. 5. As the concentration of PB increases up to $\alpha=0.956$ $T_г$ and the concentration of water vapor in the combustion products increase, this leads to a decline in $\tau_з$. A further increase inPB causes $T_г$ to decrease, although the concentration of water vapor in the combustion products continues to increase. A reduction in $T_г$ should lead to an increase in $\tau_з$, although the continuing increase in the concentration of water vapors causes it to decline, and when quantity α of the fuel changes from 0.956 to 0.65 ignition delay time remains virtually unchanged.

A further increase in PB causes a decrease in $T_г$ and the concentration of water vapor; the ignition delay time of Al begins to grow. When $T_г$ is below 2300°K the other combustion products of the model fuel probably affect quantity $\tau_з$ of Al. This change in quantity $\tau_з$ of Al as a function of quantity α in the fuel is

observed for all studied dispersions of Al, but is most pronounced when the particles have small diameters.

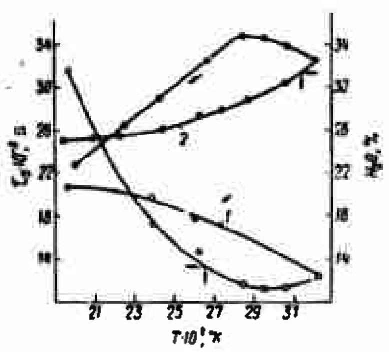

Figure 4

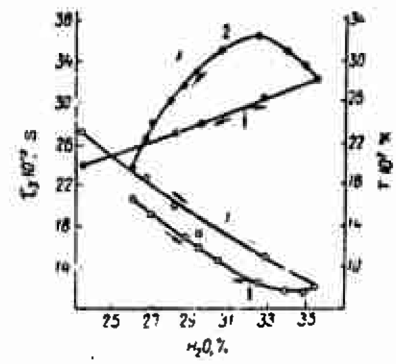

Figure 5

Figure 4. Change in ignition delay time (1) and percent concentration of water vapor (2) as functions of combustion temperature of model fuel (combustion temperature varied by changing α of fuel).

Figure 5. Ignition delay time (1) and combustion temperature of fuel (2) as a function of percent concentration of water vapors in the combustion products.